PB87-115739

Toxic Screening Models for Water Supply

(U.S.) Environmental Protection Agency
Cincinnati, OH

1986

U.S. Department of Commerce
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1. REPORT NO. EPA/600/J-86/147	2.	3. RECIPI PB87-115739
4. TITLE AND SUBTITLE TOXIC SCREENING MODELS FOR WATER SUPPLY (Journal Version)		5. REPORT DATE 1986 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) R.M. Clark,[1] W.M. Grayman,[2] J.A. Goodrich,[1]		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS 1 USEPA, Cincinnati, OH 2 Consulting Engineer, Cincinnati, OH		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. Inhouse
12. SPONSORING AGENCY NAME AND ADDRESS Water Engineering Research Laboratory- Cincinnati, OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, OH 45268		13. TYPE OF REPORT AND PERIOD COVERED Journal Article 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
Project Officer, R.M. Clark
J. Water Res. Plan. & Mgmt., ASCE 112(2):149-165, April 1986

16. ABSTRACT

Many water utilities in the United States depend upon surface water as their primary source of drinking water. Toxic screening models can be used to provide a means for identifying and assessing the pollutants likely to be in water utility source water from point and nonpoint upstream dischargers. Two case studies are presented to evaluate this concept. One is based on the stretch of Ohio River between the Kanawha River and Cincinnati, OH, and ranks the vulnerability of the utilities along this stream segment to organoleptic, toxic, and carcinogenic pollutants. The second case study uses the lower Mississippi to illustrate the use of flow routing models to predict the concentration of contaminants at downstream utilities, based on upstream industrial discharges. The important interaction between time of passage and disappearance coefficient of the pollutant is illustrated.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 18
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

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EPA/600/J-86/147
JOURNAL ARTICLE

Toxic Screening Models for Water Supply

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Abstract: Many water utilities in the United States depend upon surface water as their primary source of drinking water. Toxic screening models can be used to provide a means for identifying and assessing the pollutants likely to be in water utility source water from point and nonpoint upstream dischargers. Two case studies are presented to evaluate this concept. One is based on the stretch of Ohio River between the Kanawha River and Cincinnati, OH and ranks the vulnerability of the utilities along this stream segment to organoleptic, toxic, and carcinogenic pollutants. The second case study uses the lower Mississippi to illustrate the use of flow routing models to predict the concentration of contaminants at downstream utilities, based on upstream industrial discharges. The important interaction between time of passage and disappearance coefficient of the pollutant is illustrated.

Introduction

Many water utilities in the United States depend upon surface water as their primary source of drinking water. These utilities are therefore justifiably concerned over both the current and future quality of their water supply sources.

Implementation of treatment plant design decisions, as well as many other water resource planning decisions must necessarily be based on a knowledge of the type and concentration of pollutants and contaminants that can be reasonably expected to occur in each specific area. In as much as the drainage basins upstream of many of these supplies can encompass many square miles of land area and a wide diversity of types of economic activity, the potential types and concentrations of pollutants and contaminants in many raw water supplies are almost unlimited. Of particular concern are those contaminants that might be considered to be toxic or carcinogenic.

The Toxic Screening Models, described in this paper, provide a mechanism for identifying and assessing the pollutants that are likely to be present in surface waters used as water supplies. Specific uses of these models include the following: (1) Identification of communities whose water supplies could be vulnerable to synthetic organics resulting from industrial and municipal discharges, or urban and agricultural runoff; (2) development of designs for water treatment plants; (3) design and implementation of a water quality monitoring program; and (4) other water resource planning efforts requiring information on the water quality of surface waters.

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Note.—Discussion open until September 1, 1986. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on June 18, 1985. This paper is part of the *Journal of Water Resources Planning and Management*, Vol. 112, No. 2, April, 1986. ©ASCE, ISSN 0733-9496/86/0002-0149/ Paper No. 20504.

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Through the use of two case studies, the utility of a model-based technology for screening the types and concentrations of contaminants that might exist at any point along a stream system was examined. The case studies were conducted for: (1) The Ohio and Kanawha Rivers between Charleston, WV, and Cincinnati, OH; and (2) the lower Mississippi River between Baton Rouge and New Orleans.

Methods

Fig. 1 shows a schematic representation of the procedures used in the analysis. A stream system is composed of a set of stretches of river called "reaches." In this example, the flows and loads of reaches 4 and 5 combine at point A to contribute to the flow and loads of reach 3. Within reach 3 there are two discharges: one at point B and one at point C. For routing purposes, reach 3 is subdivided into three subsegments (subreaches) AB, BC, and CD, with point D being the downstream terminus of reach 3. For a given flow condition, the time of travel is calculated within the subsegment and the contaminant concentration at the downstream end of the subsegment is determined. These calculations are in part based on the contaminant concentration at the upstream end of the subsegment, the rate of disappearance of the contaminant, and the lateral inflow to the streams. The term "rate of disappearance" is used instead of the more common terminology of "rate of decay" because the model used in this analysis is simply a first order equation. "Disappearance" may include not only volatilization but also uptake by plants, hydrolysis, photolysis, or chemical reactions (8). Therefore, the pollutant load may not be simply decaying but could be settling into bottom sediments out of the water column.

Fig. 2 shows a profile plot of a pollutant concentration starting from an upstream discharge point to the end of the stream. The example is

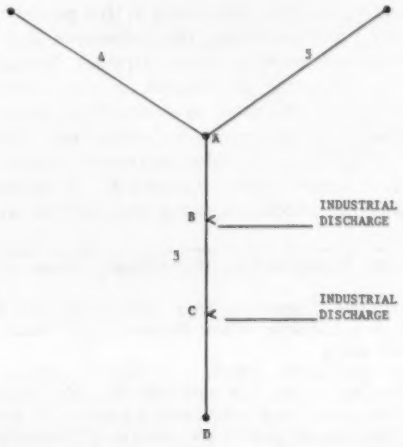

FIG. 1.—Schematic of Simple Routing Problem

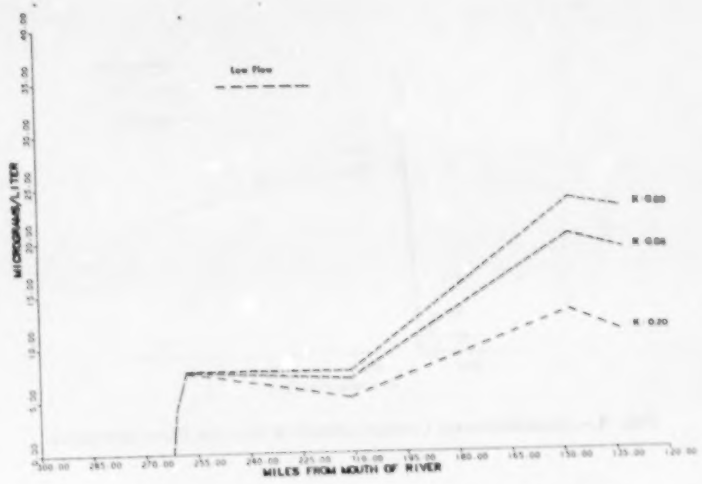

FIG. 2.—Example Profile Plot for Lower Mississippi River

for the lower Mississippi River between Baton Rouge and New Orleans using three different pollutant disappearance coefficients. An important result from this analysis is an understanding of the tradeoff that exists in flow rate, initial concentrations of pollutant and the pollutant disappearance rate. Figs. 3 and 4 demonstrate the variability of downstream pollutant concentrations based on three flow rates and for volatile and conservative contaminants respectively on the Ohio River.

In those two figures, chlorobenzene and nitrobenzene are assumed to be discharged at identical concentrations. However, chlorobenzene is assumed to have a high disappearance rate of 0.55/day compared to 0.05/day for nitrobenzene. For chlorobenzene (Fig. 3), one can see that the low flow pollutant concentrations fall far below those at average and high flows. The velocity at which chlorobenzene travels downstream during high flow conditions does not allow for much disappearance. As the time of travel decreases, the amount of disappearance decreases, leading to relatively higher concentrations of pollutant downstream than at high flows as compared to low flow. Nitrobenzene, a pollutant with a low disappearance rate, is more nearly like a conservative pollutant and most of the decrease in concentration with increased flow is due to dilution, not disappearance. Only at mile 450 can one see that the concentrations at low flow begin to drop more quickly than for high and average flows as the disappearance rate begins to have an effect.

Each of the two case studies is intended to illustrate a different point. The Ohio River case study is intended to demonstrate the use of river flow models for ranking water utilities in terms of vulnerability to upstream pollutants (2). The Lower Mississippi case study demonstrates the prediction of downstream water quality from upstream pollutant discharges. The Ohio River study used QUAL-II as the basic flow routing

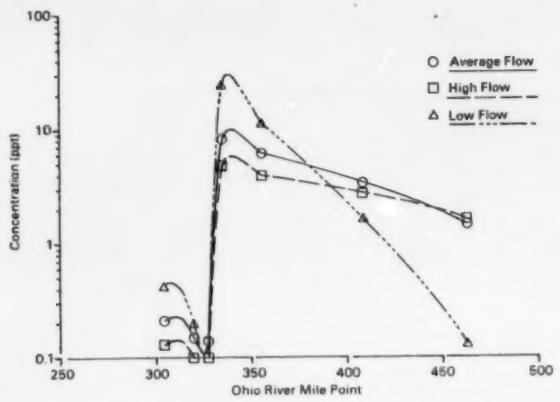

FIG. 3.—Chlorobenzene Concentrations at Various Flow Scenarios

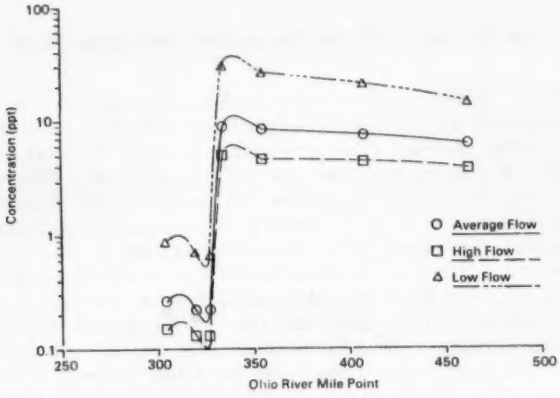

FIG. 4.—Nitrobenzene Concentrations at Various Flow Scenarios

model and the Lower Mississippi used the "Reach File" method. In the last section, QUAL-II (9) and the Ohio River Case study is used to simulate "spill events." The Ohio River Case Study is described in the following section.

Ohio River Case Study

In this case study, QUAL-II, a water quality simulation model, was used to spatially organize flow, discharge, and stream dynamics data and to simulate the types and concentration of contaminants that might exist in the Ohio River. The potential impact on public health for cities exposed to the simulated pollutant concentrations was assessed. Pollu-

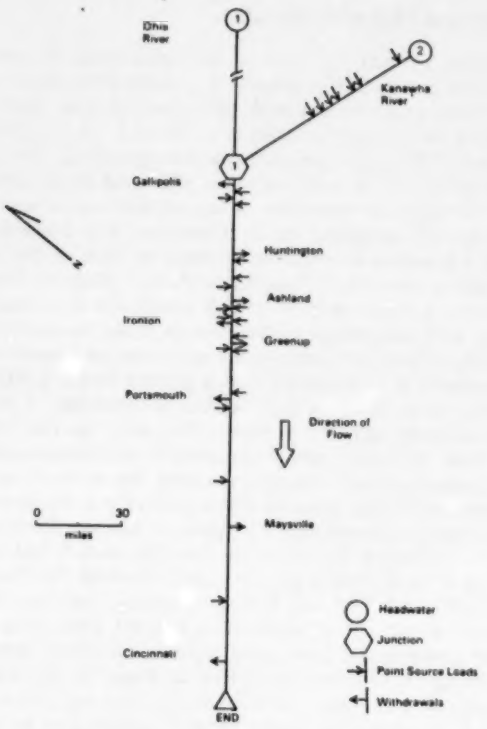

FIG. 5.—Schematic of Study Area

tant concentrations were compared to Water Quality Criteria (1), which suggest the concentrations of various pollutants that could be harmful to human health. These criteria take into account toxicity, carcinogenicity, or organolepticity (taste and odor) of the pollutants.

Applicable priority pollutants discharged in the case study area (81 out of the 129 priority pollutants) were simulated for average, high, and low flow conditions. For toxic and organoleptic pollutants, the flow scenarios are critical in determining whether a Water Quality Criteria has been exceeded. Because vulnerability to carcinogens is evaluated over years of exposure to pollutants in the drinking water, carcinogenic risk levels were initially estimated only at average flow. Fig. 5 schematically represents the case study area, including waste loads and tributaries involved in water quality modeling. In the case study, the pollutants are routed over approximately 200 stream miles (322 km). Various scenarios are used to account for seasonal variations in flow. Average flow in the Kanawha River is 25,000 cu ft/sec (cfs) (708 m^3/s) and the average Ohio River flow is 125,000 cfs (3,538 m^3/s). The smaller tributaries were considered as point loads in the analysis.

Water Quality and Health Guidelines

Water Quality Criteria for toxicity and taste and odor are based on threshold limits at which the general population would be affected by consuming water containing a pollutant reaching that level. For example, the criteria for cyanide (a toxic) is 3,770 µg/L (micrograms per liter) and for phenol is 300 µg/L (an odor causing agent) (2). The criteria level is generally the result of multiplying a risk level by a factor of ten in order to protect the more sensitive or susceptible consumers such as the very young or old, pregnant, or ill. Therefore, it is possible that small segments of a population could be affected by 10% of the criteria level specified, such as cyanide (377 µg/L) or phenol (30 g/L). Depending on the objectives of a study or level or risk acceptable to a regulator or decision-maker, any percentage of the criteria could be used (1).

Water quality criteria for carcinogens are based on a nonthreshold concept. For example, it is assumed that a person has a 0.00001 risk level of developing cancer in his or her lifetime by drinking 2 L of water with 6.6 µg/L of benzene daily for 70 years. The only "no risk" level for carcinogens is zero. Although risk is assumed to increase linearly with concentration, promoters and synergism among the contaminants could actually increase risk levels beyond those given for a single carcinogen.

Obviously many sources must be tapped to acquire the necessary data for this type of analysis. For example, the National Pollutant Discharge Elimination System (NPDES) permits, the Industrial Facilities Discharge File, Analytical Reach File and Pollutant Matrix File from EPA provide very important sources of information (3, 5, 6, 11). Data from regional authorities and government sponsored reports are other sources that can be used to bring together an "analytical package" to address the public health impacts of industrial discharges on drinking water consumers. Many other data sources or water quality models can be incorporated into this process, but they are simply a tool to use as part of the total analysis outlined in this paper.

Results of Analysis

Three scenarios were created to account for variations in flow and the pollutants discharged (81 out of the 129 priority pollutants). The three flows were 125,000 cfs (3,538 m^3/s), 220,000 cfs (6,226 m^3/s) and 35,000 cfs (990 m^3/s). The average time of travel will vary with river flow.

Using the techniques and data examined earlier, an analysis of the organoleptic, toxic, and carcinogenic pollutant exposure for various utilities in the case study area was calculated. Each of these exposures is examined in the following sections.

Organoleptic Exposure.—Table 1 summarizes organoleptic exposures for all three flow scenarios. A 10% level of exposure (10% of the criteria) and a 100% level of exposure are considered. The 10% level is presumed to represent those sensitive consumers that could be affected and the 100% level accounts for the general population exposure.

Only 2-chlorophenol and 2,4-dichlorophenol of the eleven organoleptic pollutants studied, exceed a level where sensitive consumers could be affected by taste and odor problems. One can see that only during

TABLE 1.—Summary of Organoleptic Pollutants Exceeding Guidelines

Utility (1)	Average Flow 10% level (2)	Average Flow 100% level (3)	High Flow 10% level (4)	High Flow 100% level (5)	Low Flow 10% level (6)	Low Flow 100% level (7)
Gallipolis, OH	None	None	None	None	None	None
Huntington, WV	None	None	None	None	None	None
Ashland, KY	None	None	None	None	None	None
Ironton, OH	None	None	None	None	2-Chlorophenol 2,4-Dichlorophenol	None
Greenup, KY	None	None	None	None	2-Chlorophenol 2,4-Dichlorophenol	None
Portsmouth, OH	None	None	None	None	2-Chlorophenol	None
Maysville, KY	None	None	None	None	2-Chlorophenol	None
Cincinnati, OH	None	None	None	None	2-Chlorophenol	None

TABLE 2.—Summary of Toxic Pollutants Exceeding Health Guidelines

Utility (1)	Average Flow 10% level (2)	Average Flow 100% level (3)	High Flow 10% level (4)	High Flow 100% level (5)	Low Flow 10% level (6)	Low Flow 100% level (7)
Gallipolis, OH	None	None	None	None	Cadmium	None
Huntington, WV	None	None	None	None	Cadmium	None
Ashland, KY	None	None	None	None	Cadmium Mercury	None
Ironton, OH	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Greenup, KY	Cadmium	None	Mercury	None	Cadmium Lead Chromium	Mercury
Portsmouth, OH	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Maysville, KY	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Cincinnati, OH	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury

low flow periods would the utilities have to be concerned about taste and odor problems from the priority pollutants.

Toxic Exposure.—Table 2 summarizes the exposure to toxic pollutants at the same three flows and at the 10% and 100% levels.

During low flow periods the 10% level for cadmium is exceeded at all the utilities. At Ashland, KY, the 10% level is exceeded by mercury, and at Greenup, KY, the 10% level is exceeded by lead and chromium in addition to cadmium. The simulated concentrations of mercury exceed the 100% level at Ironton, Greenup, Portsmouth, Maysville, and Cincinnati during low flow. Due to greater dilution of the pollutants at high flow, only mercury exceeds the 10% level (five utilities). At average flow, cadmium, and mercury exceed the 10% level (five utilities). Mercury tends

TABLE 3.—Vulnerability of Utilities at Various Flow Scenarios for Carcinogens

Downstream order (1)	Utility (2)	River mile (3)	Expected deaths per 100,000 at average flow[a] (4)	Expected deaths per 100,000 at high flow[a] (5)	Expected deaths per 100,000 at low flow[a] (6)
5	Greenup, KY	334.7	6.47(1)	3.75(1)	19.77(1)
6	Portsmouth, OH	355.5	5.01(2)	3.14(2)	10.42(2)
7	Maysville, KY	408.4	2.99(3)	2.36(3)	2.35(3)
8	Cincinnati, OH	462.8	1.56(4)	1.50(4)	0.56(4)
4	Ironton, OH	327.0	0.20(5)	0.13(5)	0.46(5)
2	Huntington, WV	304.3	0.19(6)	0.04(7)	0.44(6)
3	Ashland, KY	319.6	0.18(7)	0.11(6)	0.40(7)
1	Gallipolis, OH	265.8	0.02(8)	0.01(8)	0.07(8)

[a]Calculated rates.
Note: ( ) = Rank.

to exceed the 10% level for most of the utilities at all flow scenarios. Cadmium, lead, and chromium concentrations exceed the 10% level only during low and average flow scenarios.

Carcinogenic Exposure.—Because no single threshold level has been established for carcinogens, this analysis compares the simulated contaminant concentrations against the concentrations for each contaminant that signifies a 1×10^{-5} risk level of developing cancer during a lifetime. For example, a community having a concentration of 13.2 μg/L of benzene at average flow could be expected to have 2 additional deaths over 70 years per 100,000 inhabitants based on the Water Quality Criteria of 1×10^{-5} risk level for carcinogenicity at 6.6 μg/L benzene. Table 3 ranks the utilities from highest to lowest incremental death rate at different flow scenarios. As can be seen, the most downstream utility is not the utility most "at risk." Therefore, the concept that the utility with the most discharges above its intakes is most vulnerable is not true. Vulnerability depends on relative locations of intakes and outfalls.

As expected, the overall number of expected excess deaths are lower at high flow due to dilution. However, Cincinnati and Maysville risk levels are greater at high flow and average flow as compared to low flow. This unusual result is due to the compensating effects in disappearance coefficient and time of travel at the various flow scenarios. At high flows and short travel time, the dilution effect does not offset the lower amount of disappearance that has occurred. The concentrations of selected carcinogens at Maysville and Cincinnati are greater during high flow and average flow than at low flow. Huntington, Ashland, and Ironton exhibit a similar result for pollutants coming from the Kanawha River. This analysis assumes a constant pollutant load coming from industrial sources in the case study area. Pollutant loads from nonpoint sources are not likely to be constant during variable flow scenarios, thus complicating an already complex situation.

Lower Mississippi Case Study

The general purpose of the Lower Mississippi Study was to examine the concept of model-based technology for screening for the types and

concentrations of contaminants that might exist at any point along a stream system and to apply this concept to the lower Mississippi River in the vicinity of the City of New Orleans (4). A system called the Routing and Graphical Display System (5) was selected for use in carrying out the screening process and to demonstrate that this technology could be used for similar purposes at other locations through the United States.

The Routing and Graphical Display System in conjunction with the Reach File System and other data bases developed by the US EPA are a modular set of computer-based data files and programs that can be used to route pollutants and contaminants along the stream system represented in one of the data files. At present over 68,000 stream reaches are represented in the data base. The connectivity of these stream reaches has been specified so that it is possible to route flow, pollutants, and contaminants along any stream or stream system that is represented in the data base. Also, available to the Routing and Graphical Display System are data defining the location and types of wastewater discharges (industrial and municipal) to the stream systems.

Because water quality monitoring data were available from USEPA for the lower Mississippi River at Jefferson Parish (6), two types of analyses were performed: (1) A downstream-directed analysis; and (2) an upstream-directed analysis. The downstream-directed analysis involved calculating the concentration profile (i.e., the downstream-directed influence line) for a contaminant based on estimates of the quantity of the contaminant discharged at specified locations, the flow regime in the river, and the value of the disappearance coefficient. The upstream-directed analysis involved calculating the concentration profile (i.e., the upstream-directed influence line) corresponding to an upper envelope of potential concentration for a contaminant based on the concentration of contaminant at a selected downstream point, the flow regime in the river, and the estimated value of the disappearance coefficient. The disappearance coefficient is assumed constant and a first-order expression was used describing the disappearance of a contaminant from the water column by chemical, physical, or biological mechanisms.

Flow Conditions

Hydrologic Region 8 (lower Mississippi) is represented by approximately 1,800 reaches or stream segments in the Reach File System data base. The USGS has maintained a stream gaging station on the Mississippi River at Tarbert Landing, MS since 1973. This gaging station is approximately 200 miles upstream of New Orleans and 8.2 miles downstream of the Old River control structure through which approximately 30% of the streamflow is diverted to the Atchafalaya River Basin. Based on the gage data for the period of record (water years 1973–1979), the average flow at this point on the mainstem Mississippi River is approximately 540,000 cfs and the range of flow is 129,000–1,500,000 cfs. Additional flow statistics are presented in Table 4.

The distribution of daily flows for the period 1977–1979 was selected for additional analysis because it corresponds to the period of intensive water quality monitoring at Jefferson Parish by USEPA. The analysis was conducted to determine any correspondence between the variability of

TABLE 4.—Flow Statistics for Mississippi River at Tarbert Landing, MS

Statistic (1)	Based on 3 years of record 1977–1979[a] (2)	Based on period of record 7 yrs 1973–1979 (3)	Based on intermittent measurements 1936–1979 (4)
Mean	495,300	543,100	NA
Median	400,000	NA	NA
Minimum	129,000	129,000	85,000
Maximum	1,420,000	1,500,000	1,980,000

[a]Period of water quality monitoring by USEPA at Jefferson Parish.
Note: NA = Not Available.

streamflow and the variability of water quality. The probability distribution of stream flows in the Lower Mississippi River from 1977–1979 is skewed towards lower flows, resulting in a median flow (400,000 cfs) less than the mean flow of 495,000 cfs. More specifically, the 50% of flows less than the median value occur in the relatively narrow range between 129,000–400,000 cfs, while the 50% of flows greater than the median value occur in the broader range between 400,000–1,420,000 cfs. During the water quality monitoring period, 99% of the observed flows in the Mississippi River occurred in the range of 130,000–1,410,000 cfs, a ratio of 11:1.

Water Quality

Water quality data for the Lower Mississippi River is extensive and available from numerous governmental agencies. For purposes of this project, it was necessary to select a subset of this data base which related to the general area of New Orleans, containing information on a wide-range of potentially toxic substances, and could be related to known streamflow conditions. Such a data base was available from a study of organic contaminants conducted by USEPA between 1977 and 1979. During this period, USEPA monitored the raw water intake and treatment processes of a granular activated carbon (GAC) pilot treatment facility at the Jefferson Parish Water treatment plant just upstream of New Orleans (6).

The flow regimes used for the analyses were average streamflow and "low" streamflow as contained in the Reach File System data base. "Low" flow as defined in the File is an estimate of the minimum weekly flow that is expected to occur once every 10 years, i.e., the 7–10 yr low flow. The three assumed disappearance rate coefficients were 0, 0.05, and 0.2 $days^{-1}$. A value of zero was selected to demonstrate the effect of a conservative contaminant. The disappearance rate coefficient of 0.2 $days^{-1}$ results in a half-life of approximately 3-1/2 days, which corresponds to the upper end of decay rates and was selected to demonstrate the effect of rapidly decaying contaminants (3). In all cases, the concentration of pollutants in water flowing into the study area boundaries was assumed to be zero. This assumption is supported by field samples that indicate that the pollutants of interest are generally not detected in the river at

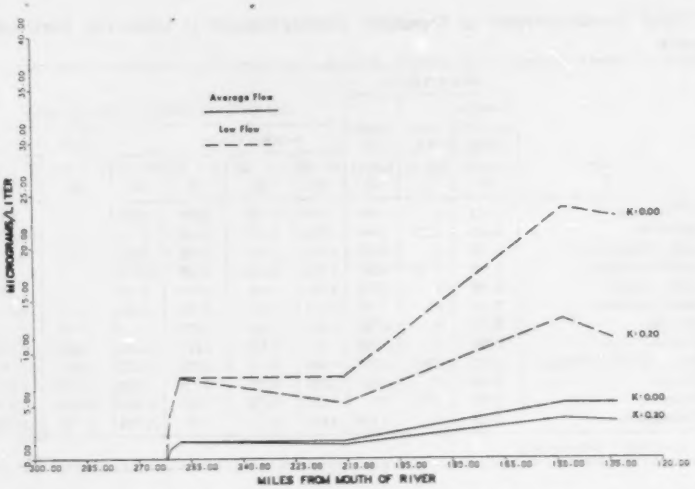

FIG. 6.—Effect of Disappearance Rate, k, and Flow on 1,2-Dichloroethane Concentrations for Lower Mississippi River

the upstream end of the study area.

The upstream-directed influence line approach was applied under the same streamflow and decay characteristics assumed for the downstream-directed influence line approach. The in situ concentration was fixed at 10 μg/L, as an example, at the end of the reach immediately upstream of New Orleans for all flow and decay conditions.

The impact of the assumed disappearance rate at constant streamflow is shown in Fig. 6 for 1,2-dichloroethane. As shown, there are no known discharges of 1,2-dichloroethane upstream of river mile 263 (just upstream of Baton Rouge) within Hydrologic Region 8, resulting in a concentration of zero above this mile point. At average flow the travel time for the entire 130 mile length of river shown is less than three days. During this short period of time, the disappearance rate has relatively little impact on contaminant concentrations. The travel time increases to 5-1/2 days under low flow conditions, which increases the sensitivity of the contaminant concentration to the value of the disappearance rate.

Comparison of Results

In order to assess the reliability and accuracy of the model and the assumptions employed, simulated concentrations of 12 contaminants were compared to values recorded at Jefferson Parish.

Selection of 12 contaminants for which actual in situ concentrations exist in the Jefferson Parish data base permitted a comparison between the simulated contaminant concentrations and actual values. The simulated concentrations and average, lower 10%, and upper 10% concentrations of in situ values are presented in Table 5.

TABLE 5.—Comparison of Simulated Concentrations to Observed Concentrations

Pollutant (1)	Jefferson Parish			SIMULATED CONCENTRATIONS (μg/L)					
	Average concentration (μg/L) (2)	Lower 10% (μg/L) (3)	Upper 10% (μg/L) (4)	Average Flows			Low Flows		
				$K = 0$ (5)	$K = 0.05$ (6)	$K = 0.2$ (7)	$K = 0$ (8)	$K = 0.05$ (9)	$K = 0.2$ (10)
Dichloromethane	0.712	0	1.900	0.093	0.076	0.044	0.408	0.291	0.113
Chloroform	0.800	0.200	1.660	0.562	0.445	0.242	2.541	1.656	0.604
Carbon Tetrachloride	0.248	0	0.250	0.007	0.006	0.004	0.033	0.023	0.009
1,2-Dichloroethane	3.585	0.480	8.600	7.412	6.116	3.507	32.635	23.318	9.080
Trichloroethene	0.188	0	0.390	1.061	0.846	0.464	4.781	3.150	1.159
Tetrachloroethene	0.075	0	0.140	0.065	0.045	0.024	0.454	0.189	0.069
Benzene	0.229	0	0.720	1.764	1.456	0.835	7.767	5.550	2.161
Toluene	0.046	0	0.210	1.417	1.169	0.670	6.238	4.459	1.736
Bis(2-Ethyl Hexyl)Phthalate	0.017	0.001	0.019	0.066	0.048	0.028	0.472	0.213	0.094
Fluorene	0.002	0	0.005	0.009	0.007	0.004	0.038	0.028	0.011
Phenol	NA	NA	NA	7.135	5.708	3.140	31.581	21.196	7.804
Nitrobenzene	0.028	0	0.070	5.631	4.649	2.664	24.794	17.716	6.899

Note: NA = Not Available.

With the exception of nitrobenzene, bis (2-ethyl hexyl) phthalate, and toluene, the simulated values reasonably approximate the range of in situ concentrations. The correspondence is best at average flow while the simulated concentrations at low flow exceed the range of actual values for some contaminants (e.g., benzene). This might be expected because actual streamflows during the monitoring program were never as low as the low flow used for simulation. An anomaly is apparent for carbon tetrachloride wherein the low flow simulated values are within the range of actual values but the average flow concentrations are not.

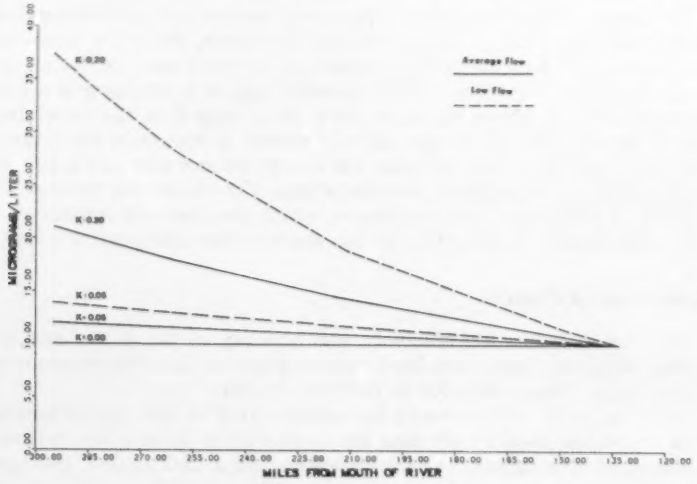

FIG. 7.—Upstream-Directed Concentration Profiles for Lower Mississippi River

This could be indicative of an "under loading" of carbon tetrachloride in the simulation compared to actual quantities discharged to the river.

The results of the upstream-directed influence line approach for a 10 μg/L contaminant concentration at Jefferson Parish illustrate the impact of the decay rate from Baton Rouge to New Orleans (Fig. 7). The flow representations for both average and low flow are constant within this length of river; thus, there is no change in dilution capacity shown in Fig. 7. The concentration profiles in Fig. 7 are a result of varying disappearance rates and the effect of differences in travel times between low and average flow. As mentioned previously, the greatest difference in concentrations between average and low flow occur at the highest disappearance rate. In this reach, average and low flow concentrations at $K = 0$ are the same. As shown in Fig. 7, the importance of the disappearance rate and contaminant loadings is readily apparent. As the disappearance rate decreases, the effect of more distant contaminant loading increases. Taken in the extreme, at a disappearance rate of zero (conservative contaminant) a contaminant discharged into the Missouri River in Montana has the same impact on water quality at New Orleans as does a contaminant discharged at Baton Rouge.

Spill Events

Most spills are industrial in origin and occur within a plant due to untrained workers, carelessness or lagoon dike failures following unfavorable weather. A large number of reported spills happen during transportation of industrial fluids including barge accidents, train derailments, and truck collisions. Barge accidents, although less frequent than the other accidents mentioned, are more threatening due to the volume and direct discharge into the river with little chance of material recovery (7).

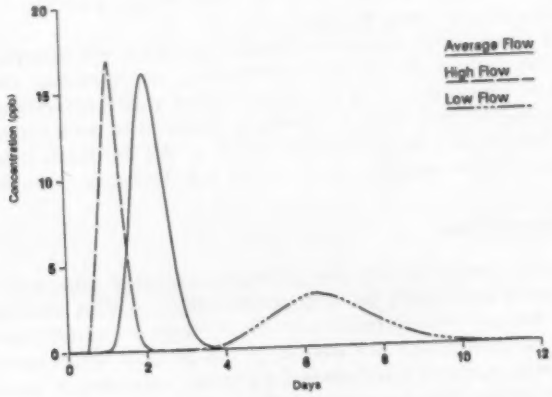

FIG. 8.—Carbon Tetrachloride Concentrations at Gallipolis, OH during Various Flow Scenarios

TABLE 6.—Priority Pollutant Discharge Simulation[a]

Utility (1)	Arrival time (days) (2)	Leave time (days) (3)	Days with contamination (4)	Peak day (5)	Peak concentration (μg/L) (6)	Storage time (days) (7)
Gallipolis, OH	2.67	16.99	14.32	7.51	289	2.0
Hungtington, WV	4.51	19.98	15.47	10.02	209	0.12
Ashland, KY	5.34	21.14	15.80	11.18	173	1.0
Ironton, OH	5.84	21.97	16.13	11.85	169	2.5
Greenup, KY	6.34	22.64	16.30	12.51	166	2.5
Portsmouth, OH	7.35	24.13	16.78	13.84	149	1.5
Maysville, KY	10.35	29.25	18.90	17.49	136	1.0
Cincinnati, OH	14.00	34.50	20.50	21.97	111	3.0

[a]60 ton spill at low flow.

QUAL-II was utilized to route a one-day 60 ton spill through the Ohio River case study area from its entry into the Kanawha River. The tradeoffs between flow, magnitude of the spill and the pollutant's disappearance rate are critical to downstream concentrations as in the daily discharge analysis. Fig. 8 shows the simulated concentrations of carbon tetrachloride as it passes Gallipolis at various flows and an assumed 0.63/day disappearance rate. The peak concentration is not the only important statistic to be concerned with in a spill event. The length of time it takes for a spill to pass a utility's intakes is also vital to a community's welfare. The shape of the curve of the spill as well as the peak must be considered in terms of how long a utility will be forced to close its intakes and allow a spill to pass. A slow moving spill although of lower peak and average concentration may pose a larger problem to a utility with limited storage capability than a more intense spill that passes quickly.

At high flows, the simulated spill would take almost 2 days to pass the Gallipolis intake. Average and low flow scenarios would require 3.5 and 9 days, respectively, to pass.

Table 6 summarizes the arrival time, leave time, the number of days with contamination, the peak concentration, storage time, and day of the peak concentration to each utility during a spill episode simulated by QUAL-II. The simulated discharge is assumed to have occurred during low flow with a disappearance rate = 0. All the times listed in the table represent the number of days after the discharge occurred.

Health Implications

As can be seen in Table 6, the pollutant discharge takes two to three weeks to pass completely by each of the utilities. Utility storage time is shown in the last column based on conversations with utility personnel. The peak concentrations are well in excess of most levels given in the Water Quality Criteria Guidelines for chronic exposure to priority pollutants. However, this exposure would only last a few days whereas the chronic exposure risk level is typically defined as low exposures exceeding 6 months.

The emphasis in examining the vulnerability of communities to the pollutants discharged for both spills and continuous discharges may lie somewhere in between chronic and acute exposure. This exposure is called subchronic and is defined in rodent studies as extending between two weeks and somewhat more than 90 days (10). This type of exposure may occur following a massive spill or succession of spills that may take many days to pass a utility's intake. Also, during seasonal periods of sustained low flow, pollutants of low disappearance rates may increase to levels comparable to a spill. During these periods small spills may take on greater significance.

Predicting Peak Downstream Concentrations

Using the results from extensive computer simulation runs, a regression equation was developed for the Ohio River case study river basin to predict concentration within a stream reach based on 296 runs of the model. The peak concentration of a spilled pollutant at a utility can be predicted by the following equation:

$$\text{Peak} = 0.74268 + 0.04236 \times \text{Init} \times e^{-K \times \text{TOT}} \quad (R^2 = 0.93) \ldots\ldots\ldots\ldots \quad (1)$$

in which Peak = peak concentration of the pollutant in μg/L; Init = initial concentration of the spill in μg/L; K = disappearance rate of the pollutant in L/day; and TOT = time of travel of the pollutant to the utility in days.

The peak concentration may vary substantially if a large tributary enters at the beginning of a reach and is not accounted for. To use Eq. 1, spill and flow information must be available to the utility manager, most of which may or may not be supplied by a regional authority. Although there is little actual empirical information regarding the fate of the priority pollutants as they travel downstream, given that the pollutant is known, it should be possible to know whether the pollutant is conservative, or highly volatile or subject to some other process affecting its disappearance rate. Having this information the manager could than make several calculations incorporating a range of disappearance rates. In this way, the utility manager would have a general idea as to when the spill will reach the utility and if the level of concentration will require extra water treatment or closure of the intakes. The equation was derived from QUAL-II simulations for the Ohio River case study area, but similar analyses could be applied to other river basins.

Conclusions

There is growing awareness of the important interactions between toxic waste discharges in surface waters and their impact on the location and management of water supply withdrawals. To properly study these interactions, it is necessary to bring together data from many sources and to study them in a spatial context. Such an analysis has been performed in this paper using available information in conjunction with existing analytical tools.

The method employed in this analysis emphasizes human health considerations as a controlling factor in toxic waste discharges and looks at

a river basin in a manner similar to the "Bubble" concept now being used in air quality regulations. The revised NPDES regulations recently proposed by EPA states that no permit will be issued to a new source or discharger if it will cause a violation of the water quality guidelines. NPDES permit limitations are established on water quality standards, but very few specific organic compounds (toxics) are written into these permits. In order for the NPDES permitting to be effective, specific organic compounds should be included that are indicative of each industries' particular discharge. The burden of proof would be on the permit applicant and that there is sufficient remaining pollutant loading capacity to cover the new discharge.

As the Water Quality Criteria Guidelines are developed, refined and possibly become law, the method developed in this paper would be directly applicable to the fulfillment of the regulations. Although a particular industry would only be interested in simulating the effects of a few relevant pollutants, the downstream utilities would be concerned with the total pollutant load of all upstream discharges. The techniques developed in this paper lend themselves readily to this kind of analysis.

This study points out that one cannot make "snap" judgments concerning the behavior of discharges. For example, because of the interactions between disappearance coefficients, time of passage and river flow scenarios one cannot always easily predict the concentration effects of a given pollutant. Pollutants with high disappearance coefficients discharged at high flow (short travel time) may have higher concentrations at a given downstream point than when discharged at lower flows (long travel time). There is no easy intuitive way to make these estimates.

Another application of this method is the addressing of water treatment strategies and sizing of facilities. Various pollutants with differing characteristics and loadings can require substantially different treatment steps. The proper sizing and choice of technology to provide safe drinking water is highly dependent on identifying the type and level of contaminants in the source of supply.

It is necessary to draw attention to the gap between water pollution control and water consumption. Because the number of toxic and carcinogenic pollutants are great and their impact on human health is important, a method to assess the vulnerability of communities to these pollutants in the drinking water is necessary.

Appendix.—References

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